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CONTROL CIRCUIT OF TWO CURRENT UNIDIRECTIONAL SWITCHES

PRIORITY CLAIM

[1] This application claims priority from French patent application No. 02/13685, filed October 31, 2002, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[2] The present invention relates generally to the control of loads supplied by an A.C. voltage and, more specifically, to the field of power dimmers of a resistive or inductive load.

[3] The present invention more specifically relates to the forming of a power dimmer based on switches bidirectional for the voltage and unidirectional for the current which are assembled in anti-parallel. A recurrent problem then concerns the supply of the respective control circuits of the two switches.

DISCUSSION OF THE RELATED ART

[4] **FIG. 1** schematically shows a conventional example of a circuit ***1*** for controlling a load ***Q*** supplied by an A.C. voltage ***Vac***. Two switches ***K1*** and ***K2*** are assembled in anti-parallel between two power terminals ***2*** and ***3*** of the dimmer, connected in series with load ***Q*** between two terminals P and N of application of A.C. voltage ***Vac***. Each switch ***K1***, ***K2*** has its control terminal connected to the output of a respective circuit ***4*** (DRIV1) and ***5*** (DRIV2), generating an appropriate control signal based on control reference values received from a common control circuit (CTRL) ***6***. Circuit ***6*** receives a power reference intended for the load, for example, by means of a potentiometer ***7*** adjusting a reference voltage exploited by circuit ***6***.

[5] **FIGS. 2A** to **2D** illustrate the operation of the power dimmer of **FIG. 1**, the principle of which is a phase angle control. **FIGS. 2A** to **2D** respectively show examples of shapes of voltage ***Vac***, of current ***IQ*** in load ***Q***, and of the on periods of switches ***K1*** and ***K2***.

[6] It is assumed that load ***Q*** is an inductive load, whereby its current is phase-shifted with respect to the A.C. voltage.

[7] The phase angle control consists of controlling the turn-on time of one of switches ***K1*** or ***K2*** according to the considered halfwave, starting from the beginning of the A.C. supply halfwave. Indeed, for each halfwave, respective turn-on times ***t1*** and ***t2***, of switches ***K1*** or ***K2*** cause the occurrence of a current in the load to be controlled. The turning-off of the on switch (time ***t1'***, ***t2'***, respectively) is controlled by a detection of the disappearing of current ***IQ*** in the load, which reproduces a triac-type operation. Since an inductive load is assumed, times ***t1'*** and ***t2'***, respectively, of switch turn-off, and thus of the disappearing of the current in the load, are shifted with respect to the zero-crossing times of A.C. voltage ***Vac***.

[8] The constraints to be fulfilled by a control circuit such as illustrated in **FIG. 1** are to provide the reference voltages to the control electrodes of the semiconductor switches, to transfer the information from control circuit ***6*** to the circuit (here, ***5***) which does not have the same voltage reference, and to detect the zero crossing of the current in the conductive switch.

[9] In conventional circuits of this type, the fulfilling of these constraints imposes use of two independent external power supplies to provide voltages ***Vcc1*** and ***Vcc2***, and thus generally of a transformer. Further, the information transfer for the stage (for example, ***5***) which does not have the same reference voltage as control circuit ***6*** requires an isolation barrier ***8*** (IB) of the optocoupler, pulse transformer, or level shifter type.

[10] Further, to enable turning off at the current zeroes in the load and thus avoiding overvoltages adversely affecting the turning-off, each circuit ***4***, ***5*** typically has an input terminal connected to a power terminal of the dimmer (respectively, terminal ***2*** for switch ***K1*** and terminal ***3*** for switch ***K2***). In practice, this generally leads to providing a sense resistor (not shown) in series with each of the switches to measure the voltage zeroes that correspond to the current zeroes. Such a resistor generates undesirable losses when the switch is in the on state.

SUMMARY OF THE INVENTION

[11] An embodiment of the present invention aims at providing a control circuit for two switches unidirectional in current and assembled in antiparallel, which circuit overcomes disadvantages of conventional circuits.

[12] Another embodiment of the present invention more specifically aims at providing a control circuit which does not require generation of independent external supply voltages.

[13] Another embodiment of the present invention also aims at providing a solution which requires no isolation barrier to transfer a control reference value.

[14] Another embodiment of the present invention further aims at avoiding the presence of a current shunt (resistor or Hall probe) in series with each switch to detect the current zero in the load.

[15] Another embodiment of the present invention also aims at providing a control circuit implementable in integrated circuit form, and compatible with the forming of a bidirectional switch in the form of a dipole, comprising two switches unidirectional in current, and of their control circuit.

[16] Another embodiment of the present invention provides a circuit for controlling two switches bidirectional for the voltage and unidirectional for the current, assembled in anti-parallel, comprising in series between two terminals of the anti-parallel assembly, two identical control stages respectively dedicated to each switch and between which is interposed a common impedance setting a phase angle for the turning-on of the switches, each stage comprising:

a controllable current source for providing a current to a control electrode of the concerned switch;

a capacitor for storing a supply voltage of at least the current source;

an element of activation/deactivation of the current source according to the voltage across the stage capacitor; and

an assembly for discharging the capacitor during the operation of the other stage.

[17] According to an embodiment of the present invention, said current source is sized to control the di/dt upon turning-on of the concerned switch.

[18] According to an embodiment of the present invention, said discharge assembly is activated from as soon as the current in the concerned switch is canceled.

[19] According to an embodiment of the present invention, the capacitor of each stage is in series with a first diode, between the impedance and the stage terminal which is the same as the terminal of the anti-parallel assembly.

[20] According to an embodiment of the present invention, a second diode of each stage connects said impedance with said terminal of the stage, which is the same as the anti-parallel assembly terminal.

[21] According to an embodiment of the present invention, a third diode connects the control electrode of the switch of each stage to the electrode of said capacitor, so that said discharge assembly also discharges the control electrode of the stage switch.

[22] According to an embodiment of the present invention, the respective switch of each stage provides the power supply necessary to all stage components.

[23] According to an embodiment of the present invention, said activation/deactivation element activates said current source with which it is associated when the voltage across the capacitor of the stage becomes greater than a first threshold, itself greater than the threshold voltage of the concerned switch.

[24] According to an embodiment of the present invention, said comparator deactivates said current source with which it is associated when the voltage across the capacitor of the stage becomes greater than a second threshold, itself preferably smaller than said threshold voltage of the concerned switch.

[25] According to an embodiment of the present invention, each discharge assembly comprises a first transistor in parallel with the stage capacitor, the control electrode of the first transistor being connected, via a second transistor, to said impedance.

[26] According to an embodiment of the present invention, said activation/deactivation element of each stage is formed of a comparator receiving on a first input the voltage across the stage capacitor and on a second input a reference voltage, said comparator being supplied by the voltage across the capacitor of the concerned stage.

[27] According to an embodiment of the present invention, said impedance is formed of a potentiometer.

[28] According to an embodiment of the present invention, said impedance is formed of a first resistor in parallel with a second switchable resistor, said first resistor having a much greater value than the second one.

[29] An embodiment of the present invention also provides a power dimmer for a load.

[30] An embodiment of the present invention also provides a circuit for controlling a motor.

[31] Features and advantages of the present invention will be discussed in detail in the following non-limiting description of specific embodiments in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[32] **FIG. 1**, previously described, shows a conventional example of a circuit for controlling two unidirectional switches assembled in anti-parallel;

[33] **FIGS. 2A** to **2D** illustrate, in the form of timing diagrams, the operation of the circuit of **FIG. 1**;

[34] **FIG. 3** shows an embodiment of a control circuit according to the present invention;

[35] **FIGS. 4A** to **4J** illustrate, in the form of timing diagrams, the operation of the circuit of **FIG. 3**;

[36] **FIGS. 5A** to **5D** show examples of switches bidirectional for the voltage and unidirectional for the current, controllable by a circuit such as illustrated in **FIG. 3**;

[37] **FIG. 6** shows an alternative embodiment of the element for setting the power control reference of the circuit of **FIG. 3**; and

[38] **FIGS. 7A** to **7J** illustrate the operation of a control circuit according to an embodiment of the present invention on an inductive load.

DETAILED DESCRIPTION

[39] Same elements have been designated with same reference numerals in the different drawings. For clarity, only those circuit elements which are necessary to the understanding of the present invention have been shown in the drawings and will be described hereafter. In particular, the load controllable by the circuit embodiments of the present invention has not been detailed, the embodiments of the present invention applying whatever the resistive and/or inductive load to be controlled by an A.C. supply voltage, and of which the operating power is desired to be modulated according to a reference value.

[40] **FIG. 3** shows an embodiment of a circuit for controlling two switches according to the present invention.

[41] As previously, two switches ***K1*** and ***K2*** unidirectional in current are connected in anti-parallel between two terminals ***2*** and ***3*** defining a switch bidirectional in voltage and current, assembled in series with a load ***Q*** between two terminals P and N of application of an A.C. voltage ***Vac***. In the example of **FIG. 3**, it is assumed that switches ***K1*** and ***K2*** are MBS-type semiconductor components, also called RGIGBT. As will be detailed in relation with **FIG. 5A**, such switches have the same operation as an IGBT transistor, integrating a protection diode, which makes them bidirectional for the voltage. This diode is symbolized by a line on the switch collector.

[42] According to this embodiment of the present invention, each switch ***K1***, ***K2*** is associated with a dedicated control stage ***10***, ***20***. Stages ***10*** and ***20*** are identical and are connected to each other by a common impedance ***30*** setting the phase angle for the switch turning-on. In **FIG. 3**, the common impedance is formed of a potentiometer ***30*** having its two terminals respectively connected to stages ***10*** and ***20***. Each stage ***10***, ***20*** has a tripolar structure, that is, it comprises two terminals,

respectively ***11*** and ***12*** and ***21*** and ***22***, connected between common impedance ***30*** and the respective emitter of MBS transistors ***K1*** and ***K2***, and an output terminal, ***13*** and ***23***, respectively, for respectively controlling switches ***K1*** and ***K2***. A difference with respect to the conventional control circuit of **FIG. 1**, for which the stages assigned to the respective switches require five terminals, can already be noted.

[43] The structure of a control stage according to this embodiment of the present invention will be described hereafter in relation with control stage ***10*** of switch ***K1***. Control stage ***20*** of switch ***K2*** exhibits exactly the same structure and its components are referenced in **FIG. 3** by reference numerals starting with number 2 and not with number 1.

[44] Stage ***10*** comprises a controllable current source ***14*** having its output connected to control terminal ***13*** of switch ***K1*** and which is intended to control its turning on. For example, current source ***14*** is a constant current source controlled by an activation/deactivation element ***15***. According to this embodiment of the present invention, element ***15*** activates current source ***14*** according to the voltage across a capacitor ***C11*** functionally in series with potentiometer ***30*** between terminals ***2*** and ***3*** of the switch, the impedance of potentiometer ***30*** thus conditioning the phase angle for the turning-on of switch ***K1***.

[45] In the example of **FIG. 3**, the current source activation/deactivation element is formed of a hysteresis comparator ***16*** having a first input connected to the electrode of capacitor ***C11*** opposite to terminal ***3*** and having a second input receiving a reference voltage ***Vref*** provided, for example, by a zener diode of a circuit for generating a voltage reference of bandgap type.

[46] According to this embodiment of the present invention, capacitor ***C11*** also has the function of supplying stage ***10*** during the halfwaves (for example, positive) assigned to stage ***10***. Thus, capacitor ***C11*** provides the supply voltage of current source ***14*** enabling it to activate switch ***K1*** as well as the supply voltage of the activation/deactivation element (more specifically, of comparator ***16***), the respective supply terminals of which are connected to terminals ***17*** and ***12*** of capacitor ***C11***.

[47] To assign stage ***10*** to a single type of halfwaves, here, positive halfwaves, a diode ***D12*** connects terminal ***11*** of impedance ***30*** to electrode ***17*** of the capacitor. This diode ***D12*** having its anode connected to terminal ***11*** is forward biased during positive halfwaves only. To enable flowing of the current despite the presence of the diode (***D22***) associated with stage ***20***, a diode ***D21*** of stage ***20*** connects its terminals ***21*** and ***22*** during positive halfwaves, the anode of diode ***D21*** being connected to terminal ***22***. On the side of stage ***10***, a diode ***D11*** is connected between terminals ***11*** and ***12***, its anode being connected to terminal ***12***.

[48] According to this embodiment of the present invention, stage ***10*** also comprises an assembly ***18*** for discharging capacitor ***C11*** during the halfwave when this stage is not conductive, to reset the stage to prepare for the next positive halfwave. During this discharge, it is also necessary to discharge the gate of switch ***K1*** if said switch is of insulated-gate type. For this purpose, terminal ***13*** is then connected to electrode ***17*** of capacitor ***C11*** by a diode ***D13*** having its anode connected to terminal ***13***. Thus, the gate of switch ***K1*** will be discharged at the same time as capacitor ***C11***.

[49] In the example of **FIG. 3**, assembly ***18*** is formed of a first PNP-type bipolar transistor ***T12*** connected between electrodes ***17*** and ***12*** of capacitor ***C11***, its emitter being connected to electrode ***17***. The base of transistor ***T12*** is connected, preferably via a biasing resistor ***R12***, to the collector of a bipolar NPN-type transistor ***T11*** having its emitter connected to terminal ***11***, that is, outside of stage ***10*** to enable conduction during halfwaves of the opposite sign. The base of transistor ***T11*** is connected, preferably via a biasing resistor ***R11***, to terminal ***12*** of stage ***10***.

[50] It can already be seen that the control circuit of this embodiment of the present invention, in its version such as illustrated in **FIG. 3** where the control element is a potentiometer, appears in the form of a completely autonomous dipole.

[51] **FIGS. 4A** to **4J** illustrate, in timing diagrams, the operation of the circuit of **FIG. 3**. These timing diagrams respective show examples of shapes of signals ***Vac***, ***IQ***, ***VC11***, and ***V13*** respectively representing the voltage across capacitor ***C11*** and the gate bias voltage of switch ***K1***, ***VC21*** and ***V23***, respectively

representing the voltage across capacitor ***C21*** and the gate voltage of switch ***K2***, the conduction periods of circuit ***18*** and of diode ***D11***, the conduction periods of diode ***D12***, the conduction periods of diode ***D13***, the conduction periods of circuit ***28*** and of diode ***D21***, the conduction periods of diode ***D22***, and the conduction periods of diode ***D23***.

[52] **FIGS. 4A** to **4J** illustrate the circuit operation to a control a purely resistive load ***Q***. Another example applied to an inductive (or resistive and inductive) load will be described hereafter in relation with **FIGS. 7A** to **7J**.

[53] Initially, capacitors ***C11*** and ***C12*** are discharged and all diodes and transistors are off. It is assumed that at a time ***t0***, A.C. voltage ***Vac*** is applied across the system and it is assumed, to simplify the description, that this time corresponds to the beginning of a positive halfwave. The following description will however show that the power-on time has no adverse incidence upon the operation. To simplify, no account will be taken of the forward voltage drops of the different diodes (generally, on the order of 0.6 volts) when they have no influence upon the circuit operation.

[54] As soon as the positive halfwave starts (time ***t0***), diodes ***D21*** and ***D12*** are forward biased (**FIG. 4F** and **FIG. 4H**) while diodes ***D22*** and ***D11*** are off (**FIG. 4E** and **FIG. 4I**). Further, since diode ***D21*** is on, stage ***28*** also conducts. For the time being, it should only be noted that the fact for this stage to conduct forces a turning-off of switch ***K2*** and a discharge of capacitor ***C22***. The operation of the discharge assembly will be detailed hereafter in relation with the operation of stage ***10***. Similarly, transistors ***T11*** and ***T12*** of assembly ***18*** are both off since diode ***D11*** is off. As a result, diode ***D13*** is off since an initially low voltage (voltage of terminal ***12***) is assumed for the gate of switch ***K1***.

[55] A charge current of capacitor ***C11*** thus flows from terminal ***2*** to terminal ***3*** through diode ***21***, potentiometer ***30*** and diode ***D12***. The rapidity at which capacitor ***C11*** charges (**FIG. 4C**) depends on the resistance of element ***30***. Capacitor ***C11*** and the variation range of resistance ***30*** are sized for the voltage across capacitor ***C11*** to be sufficient to supply comparator ***16*** and current source ***14***. Source ***14*** may have any structure, provided that it is controllable. For example, it

circuit and potentiometer ***30*** to charge capacitor ***C22*** during this negative halfwave. On the side of stage ***20***, the operation described hereabove in relation with the positive halfwave is reproduced during the negative halfwave.

[62] On the side of stage ***10***, the conduction of diode ***D11*** activates assembly ***18*** for discharging capacitor ***C1***. In fact, the conduction of diode ***D11*** turns on transistor ***T11*** and the potential difference existing across capacitor ***C11*** enables turning-on of transistor ***T12***, which then causes the discharge of capacitor ***C11***. Further, since the gate of switch ***K1*** is initially at voltage ***V13***, identical to the voltage across capacitor ***C11***, diode ***D13*** is forward biased, which enables discharge of the gate of switch ***13*** to prepare it for the next halfwave.

[63] In fact, capacitor ***C11*** discharges little after the beginning of the negative halfwave, that is, as soon as diode ***D11*** is on. In other words, this occurs as soon as the voltage between terminals ***2*** and ***3*** of the control circuit becomes greater than –2*Vf, where Vf represents the voltage drop of a forward diode, here –(VfD11+VfD22), where VfD11 and VfD22 represent the respective forward voltage drops of diodes ***D11*** and ***D22***. Upon turning-off of switch ***K1***, no current peak occurs since the turning-off occurs while the voltage across the capacitor is negative.

[64] In **FIG. 4**, it has been considered that capacitor ***C11*** was fully discharged at a time ***t17***. From this time on, diode ***D13*** turns off, the gate of switch ***K11*** being discharged. Upon discharge of capacitor ***C11***, comparator ***16*** switches to turn off current source ***14***, before capacitor ***C11*** is fully discharged.

[65] The low switching threshold (decreasing voltage ***VC11***) of comparator ***16*** is, preferably, smaller than threshold voltage ***Vth*** of switch ***K1*** for reasons of turn-off stability of the current source. Accordingly, the hysteresis of comparator ***16*** is chosen for threshold ***Vth*** to range between switching threshold ***Vref*** in the increasing direction and the low switching threshold in the decreasing direction.

[66] At the end of a negative halfwave, control stage ***10*** conducts again. Said stage restarts as in the previously-described initial stage since all its components are found discharged by the discharge of capacitor ***C11***. The only difference is that diode ***23*** turns on at the beginning of the second positive halfwave while it was off in

may be a current source formed from a MOS transistor current mirror, supplied by the voltage across capacitor ***C11***.

[56] At a time ***t3***, the voltage across capacitor ***C1*** reaches reference voltage ***Vref*** of comparator ***16***. This results in a switching of this comparator, which activates current source ***14***. Assuming a constant current provided by source ***14***, the voltage of gate ***13*** of switch ***K1*** starts increasing from time ***t3*** and its increase continues until it reaches, at a time ***t4***, the voltage of terminal ***17***, that is, voltage ***VC11***. From time ***t4*** on, gate voltage ***V13*** of switch ***K1*** follows the shape of voltage ***VC11*** across capacitor ***C11***.

[57] Between times ***t3*** and ***t4***, as soon as voltage ***V13*** reaches threshold voltage ***Vth*** of switch ***K1*** (time ***t5***), said switch turns on and a current starts flowing through load ***Q*** via switch ***K1*** (**FIG. 4B**). The growth of current ***IQ*** in the load occurs without any peak, due to current source ***14*** which controls di/dt at the turning on of switch ***K1***. It is assumed that at a time ***t6***, current ***IQ*** in the load has joined the shape of A.C. voltage ***Vac***, switch ***K1*** having reached its saturated operating area.

[58] According to this embodiment of the present invention, for this condition to be fulfilled, voltage ***Vref*** (more specifically, the switching level of comparator ***16*** in the increasing direction of the voltage of capacitor ***C11***) is chosen to be much greater than threshold voltage ***Vth*** of switch ***K1***.

[59] At time ***t6*** when switch ***K1*** is fully on, terminals ***2*** and ***3*** of the control circuit are short-circuited, which turns off diodes ***D21*** and ***D12*** and, accordingly, stage ***28***.

[60] Stage ***10*** is then isolated from the A.C. power supply and from the load. Accordingly, capacitor ***C11*** does not discharge. In the example of **FIG. 3**, switch ***K1*** is an MBS, that is, an insulated-gate component. The discharge of capacitor ***C11*** linked to the gate control of this switch is thus negligible.

[61] At time ***t10*** when the positive halfwave of voltage ***Vac*** ends, nothing occurs. Indeed, although the voltage drops in the different diodes have been neglected, the beginning of the negative-halfwave period of operation begins when the diodes ***D11*** and ***D22*** turn on, and thus when a current flows through the control

the first halfwave since a non-supplied initial state of the circuit had been considered.

[67] A variation in resistance ***30*** results in modifying the charge aspect of capacitors ***C11*** and ***C22*** according to the halfwaves and, accordingly, times ***t3*** and ***t13*** of beginning of the conduction of switches ***K1*** and ***K2*** for each halfwave.

[68] An advantage of this embodiment of the present invention is that the control circuit requires no external supply circuit and in particular no transformer.

[69] Another advantage of this embodiment of the present invention is that the detection of the current zero performed by reading of the reverse voltage avoids occurrence of overvoltages at the turning-off of the switches on an inductive load.

[70] Another advantage of this embodiment of the present invention is that the di/dt upon turning-on of the switches is controlled by current sources ***14***, ***24***.

[71] Another advantage of this embodiment of the present invention is that it requires no isolation barrier to ensure the control of one or the other of the stages.

[72] Other advantages of this embodiment of the present invention are the simplicity of the control circuit and the symmetry of the obtained control whatever the halfwave sign.

[73] Another advantage of this embodiment of the present invention is that the provided control circuit is entirely integrable (except however for the control potentiometer). Indeed, as appears from the above-described operation, none of the control circuit diodes (especially diodes ***D11***, ***D12***, ***D21*** and ***D22***) needs holding a high voltage. Indeed, the only periods (times ***t6*** to ***t10*** and ***t16*** to ***t0***) during which the current flowing through the control circuit is not absorbed by potentiometer ***30*** are the periods where one of switches ***K1*** or ***K2*** is fully on (saturated), whereby terminals ***2*** and ***3*** are short-circuited.

[74] Another advantage of this embodiment of the present invention is that he power dimmer thus formed requires neither inductance, nor filtering capacitor, nor external supply. This embodiment of the present invention is thus perfectly compatible with the forming of a dimmer in the form of a dipole.

[75] **FIGS. 5A** to **5D** illustrate examples of switches ***K1*** or ***K2*** likely to be used in a control circuit according to an embodiment of the present invention. **FIG. 5A** shows the diagram of an MBS-type transistor ***40*** such as shown in relation with **FIG. 3**. Such a component has the advantage of being unidirectional in current while being bidirectional for the voltage, that is, holding the reverse voltage due to an integrated diode, symbolized by a line ***41*** in **FIG. 5A**. As a result, the on-state voltage drop is limited to the saturation collector-emitter voltage ***VCEsat*** of the component.

[76] **FIG. 5B** illustrates a second example of a switch ***42*** formed of an IGBT transistor ***43*** in series with a diode ***44***. The diagram of **FIG. 5B** is an equivalent of MBS transistor ***40*** of **FIG. 5A**, but in which the on-state voltage drop corresponds to the sum of voltage ***VCEsat*** of IGBT transistor ***43*** and of voltage ***VF*** of forward diode ***44***.

[77] **FIG. 5C** shows a third example of a switch ***45***, here formed of a MOS transistor ***46*** in series with a diode ***47***.

[78] **FIG. 5D** illustrates a fourth example of a switch ***48*** formed of an NPN-type bipolar transistor ***49*** in series with a diode ***50***.

[79] Any structure of a switch unidirectional for the current and bidirectional for the voltage (even though the voltage bidirectionality is brought by a separate diode introducing an additional voltage drop) may be used. The only possible precaution is, in the case of a bipolar transistor (**FIG. 5D**) or more generally of a current-controlled switch, is to provide a capacitor ***C11*** of sufficient capacitance to ensure the provision of the base current to transistor ***49*** during its entire conduction period, while maintaining the supply of comparator ***16*** and of current source ***14***. In the case where it is not desired to discharge the switch control electrode, diode ***D13*** (or ***D23***) may be omitted.

[80] **FIG. 6** shows a second embodiment of an element ***60*** forming a common impedance between stages ***10*** and ***20*** of **FIG. 3**. This embodiment can replace the potentiometer ***30*** of **FIG. 3**, and is intended to enable control of the power dimmer by a signal CTRL external to the actual power dimmer.

[81] According to this embodiment, impedance ***60*** comprises, in parallel between its terminals ***21*** and ***11***, a protection resistor ***Rp*** and a series association of a resistor ***Rc*** with a switch ***K*** controlled by external signal CTRL. The function of resistor ***Rc*** is to limit the current in diodes ***D12***, ***D21***, and ***D22***, ***D11*** respectively, when switch ***K*** is on. This enables allowing a turning-on of switch ***K*** at any time with respect to supply voltage ***Vac***. The function of resistor ***Rp*** is to guarantee an automatic turning-off at the current zero even if switch ***K*** has been off meanwhile under the effect of a disappearing of signal CTRL. It will be ascertained to choose a resistance ***Rp*** much higher than resistance ***Rc*** to enable flowing of the current in the branch of resistor ***Rc*** when the switch is on. Further, resistance ***Rp*** will have to be sufficiently high to avoid the charge of capacitors ***C11*** and ***C21*** reaching level ***Vref*** in a half A.C. power supply period when switch ***K*** is off.

[82] **FIGS. 7A** to **7J** illustrate, in timing diagrams showing the same signals as **FIGS. 4A** to **4J**, the operation of a control circuit according to an embodiment of the present invention, connected to an at least partially inductive load ***Q***. The main difference with respect to the timing diagrams of **FIGS. 4A** to **4J** is that the shape of current ***IQ*** in the load has a growth in which the di/dt is naturally limited by the load inductance.

[83] Another difference is that due to the phase shift introduced by the load inductance on the times (***t0'***, ***t10'***, **FIG. 7B**) of current cancellation therein with respect to the zero crossing times (***t0***, ***t10***, **FIG. 7A**) of voltage ***Vac***, the charge of capacitor ***C11*** or ***C21*** is performed faster. As a result, time ***t3*** of beginning of the operation of current source ***14*** is closer to time ***t0'*** than it is to time ***t0*** in a purely resistive load.

[84] For the rest, the operation of the control circuit can be deduced from the previous discussion in relation with a resistive load.

[85] It should be noted that for an inductive load, this embodiment of the present invention requires no shunt in series with the load to detect the zero crossing of the current in the load. Accordingly, the phase shift linked to the inductive load is used to guarantee a turning-off of the switches at a time when the voltage thereacross is negative. This induces a natural detection of the current zero. An

advantage then is that overvoltages are avoided at the turning-off of thyristor-type switches. Another advantage is that this reduces the losses linked to the shunt resistor, in series with the switch, in conventional circuits.

[86] The control impedance of this embodiment of the present invention intervenes on an inductive load in the same way as for a resistive load to control the charge of capacitor ***C11*** or ***C21*** according to the halfwave, and thus the interval between times ***t'0*** and ***t3*** and ***t'10*** and ***t13***, respectively. Since once the capacitor has been charged and comparator ***16*** has been triggered, the switch control is set by current source ***14***, the operation of which is independent from impedance ***30***, the setting of time ***t3*** effectively amounts to setting time ***t5*** of beginning of the load conduction.

[87] Of course, the present invention is likely to have various alterations, modifications, and improvements which will readily occur to those skilled in the art. In particular, the practical implementation of the current sources and of the comparators is within the abilities of those skilled in the art based on the functional indications given hereabove. It should however be reminded that these components do not require a supply distinct from that brought by capacitors ***C1*** and ***C21*** provided by the circuit of the present invention.

[88] Further, the sizing of the capacitors and resistors, as well as of the semiconductor components, is within the abilities of those skilled in the art according to the application and to the desired operation.

[89] Further, it should be noted that the present invention may form a power dimmer not only for lamp-type circuits, but also to ensure the control of motors due to its high-performance operation on an inductive load.

[90] Finally, although according to a preferred embodiment, the present invention provides a symmetrical operation with identical voltages ***Vref*** for comparator ***16*** and for comparator ***26***, it does not exclude a dissymmetry according to the positive or negative halfwave, simply by modifying the voltages ***Vref*** used.

[91] Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and the scope of the

present invention. Accordingly, the foregoing description is by way of example only and is not intended to be limiting.